# AFRL-RY-WP-TM-2009-1057

# ALGEBRAIC TOPOLOGY AND NEUROSCIENTIFIC DATA - NEOVISION 2

**Gunnar Carlsson**

**Stanford University**

**FEBRUARY 2009**
**Final Report**

**Approved for public release; distribution unlimited.**

***See additional restrictions described on inside pages***

**STINFO COPY**

**AIR FORCE RESEARCH LABORATORY**
**SENSORS DIRECTORATE**
**WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7320**
**AIR FORCE MATERIEL COMMAND**
**UNITED STATES AIR FORCE**

# NOTICE AND SIGNATURE PAGE



AFRL-RZ-WP-TM-2009-1057 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH THE ASSIGNED DISTRIBUTION STATEMENT.

*//signature//

BRADLEY J. PAUL, Project Engineer
Advanced Sensors Components Branch
Aerospace components Division

//signature//

BRADLEY J. PAUL, Chief
Advanced Sensors Components Branch
Aerospace components Division

//signature//

TODD A. KASTLE, Chief
Aerospace components Division
Sensors Directorate



*Disseminated copies will show "//signature//" stamped or typed above the signature blocks.

# REPORT DOCUMENTATION PAGE

*Form Approved OMB No. 0704-0188*



**1. REPORT DATE** ***(DD-MM-YY)***
February 2009

**2. REPORT TYPE**
Final

**3. DATES COVERED** ***(From - To)***
15 September 2006 – 30 December 2008

**4. TITLE AND SUBTITLE**
ALGEBRAIC TOPOLOGY AND NEUROSCIENTIFIC DATA – NEOVISION 2

**5a. CONTRACT NUMBER**
FA8650-06-1-7629

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**
69199F

**6. AUTHOR(S)**
Gunnar Carlsson

**5d. PROJECT NUMBER**
ARPS

**5e. TASK NUMBER**
ND

**5f. WORK UNIT NUMBER**
ARPSNDB7

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Stanford University
340 Panama Street
Stanford, CA 94305-6203

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Air Force Research Laboratory
Sensors Directorate
Wright-Patterson Air Force Base, OH 45433-7320
Air Force Materiel Command
United States Air Force

**10. SPONSORING/MONITORING AGENCY ACRONYM(S)**
AFRL/RYDI

**11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)**
AFRL-RY-WP-TM-2009-1057

**12. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution unlimited.

**13. SUPPLEMENTARY NOTES**
PAO case number 88 ABW-09-1296; cleared 03 April 2009.

**14. ABSTRACT**
This work applied methods from computational topology to understand the behavior of populations of neurons in the Macaque primary visual cortex using embedded electrode arrays. The methods were additionally adapted to test the behavior of technology produced by Irvine Sensors, in which it is hoped to construct an artificial visual pathway. The results obtained demonstrated the presence of strong correlations of a particular kind in the electrode array data.

**15. SUBJECT TERMS**
Computational topology, homology, Betti numbers, primary visual cortex, correlations

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT: | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON (Monitor) / 19b. TELEPHONE NUMBER *(Include Area Code)* |
|---|---|---|---|---|---|
| Unclassified | Unclassified | Unclassified | SAR | 10 | Bradley J. Paul / (937) 255-4557, ext. 3442 |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std. Z39-18

## Neovision 2 - Final Report

The achievements of the Stanford node in the Neovision 2 project are as follows.

**V1 population activity:** One of the goals of the project was to obtain some understanding of the behavior of populations of neurons in the Macaque primary visual cortex. An important initial question concerning the behavior of neuron arrays is to describe or attempt to characterize the behavior of the arrays in the absence of stimulus. Long term, one expects that such understanding is key to understanding how the neurons function collaboratively to encode stimuli. Earlier work by the Grinvald group in Israel had announced that they had found correlation between the behavior in the absence of stimuli and in the presence of stimuli, which they interpreted as suggesting that the unstimulated, or spontaneous activity, is really cycling through a family of states which occur in the course of stimulation. We were unable to reproduce the correlation in the paper, and decided to use our computational topology framework to obtain both a verification of the results stated in the Grinvald group and possibly more refined information about the states. We did this by constructing a point cloud using data provided to us by Dario Ringach using electrode arrays implanted in the Macaque V1. The arrays contained 96 electrodes, and the data from these electrodes is transformed using standard signal processing methods into spike trains for a family of neurons. We selected from them a much smaller set of high activity neurons. From the spike trains attached to these neurons, we built point clouds using various metrics on the space of spike trains. Finally, we applied the PLEX software for computing persistent homology on point clouds, using many different choices of landmark points in the corresponding witness complexes. We performed these computations in three separate regimes. The first is the (a) spontaneous situation, where the animal is viewing a gray background, the second (b) is where the animal is viewing a movie as input, and the third (c) is a synthetic situation based on a Poisson model for firing of neurons. The results were quite striking. First, both regimes (a) and (b) exhibit non-trivial topological behavior, i.e. non-trivial first and second Betti numbers, with substantial frequency, and (c) does not. This was verified by performing extensive simulation with model (c), which produces substantial topological behavior with very low frequency. Secondly, though, a distinction between (a) and (b) also appeared, in that the topologies represented were substantially different. Specifically, in regime (a), circles and spheres appeared with comparable frequencies, and in regime (b), circles were much more highly represented than spheres. This says that although our methods show certain similarities between the spontaneous and stimulated regimes, as was predicted by the Grinvald paper, they also are able to distinguish between the two. We believe that this demonstrates the power of the topological technique, and also suggest some hypotheses concerning what is being represented by the topology. The results of this work were published in Journal of Vision, and were also presented as a poster at COSYNE2008, an important neuroscience conference.

G. Singh, F. Memoli, T. Ishkhanov, G. Carlsson, G. Sapiro and D. Ringach, *Topological Structure of Population Activity in Primary Visual Cortex*, Journal of Vision, Volume 8, Number 8, Article 11, pp. 1-18, 2008.

**Hippocampus and place fields:** We took on another project related to vision, specifically the behavior of the hippocampus. This is joint work with Yuri Dabaghian of University of Calfornia, San Francisco. It has been submitted to COSYNE2009. The work can be summarized as follows.

The crucial role of the hippocampus in creating a spatial representation of the environment and in forming spatial memories is well known. Rodent hippocampal neurons are generally referred to as "place cells," a name derived from the fact that each active neuron tends to fire in a restricted region of the animal's environment. This property has led to the general statement that the rodent hippocampus codes for "space" but it is not clear exactly what is meant by this claim. In particular, space can be thought of in terms of two types of representations: topological (e.g. connectivity of locations) and geometric (e.g. distances and angles). Current theories suggest that the hippocampus explicitly represents geometric elements of space derived from a path integration process that takes into account distances and angles of self motion information.

This hypothesis has difficultly explaining the results of several experimental studies that indicate that the hippocampal spatial map is invariant with respect to a significant range of geometrical transformations of the environment. This invariance suggests an alternative framework where hippocampal neural activity is best understood as representing the topology of the animal's environment. We therefore suggest that the actual role of the hippocampus is to encode topological memory maps, where the patterns of ongoing neural activity represent the connectivity of locations in the environment or the connectivity of elements of a memory trace.

From a computational perspective, this hypothesis suggests a specific approach to interpreting the temporal activity patterns of place cells where the temporal ordering of spiking from hippocampal neural ensembles is the key determinant of the spatial information communicated to downstream structures.

If so, then the variation seen in hippocampal firing rates should be limited to a range that preserves the global topological information encoded in the ensemble spike trains. More generally, if the overall approach to spatial information analysis is correct, the experimentally observed parameters of firing activity must guarantee the topological stability the hippocampal map.

We therefore investigate the robustness of the hippocampal topological map with respect to independent variations of various place cell activity parameters, such as the firing rate and the distribution of sizes of place fields. We used the Persistent Homology method [4], applied to simulated data. Using the simulated data is important in our approach because it allows us to probe the complete stability range for each parameter independently and hence to establish theoretically the range of spiking parameters that lead to topological stability. After establishing the theoretical range of topological stability of the hippocampal map, we then compare the results with the values of the parameters that were observed experimentally. We believe that this type of comparison can provide fundamental insights into the parameter ranges seen in experimental studies.

Yuri Dabaghian, Facundo Memoli, Gurjeet Singh, Loren Frank, and Gunnar Carlsson, *Topological stability of the hippocampal spatial map*, submitted to COSYNE2009

**Testing of Irvine Sensors output:** We used the topological methods to provide corroboration that software and hardware produced by Irvine Sensors was correct. The tests in some cases

revealed some issues, which were readily resolved.

We were disappointed at the delays in producing 2-photon data. We understand, though, that delays are intrinsic in this kind of work. The current status is that although the technology is producing data, it is still very difficult to calibrate it in such a way that even simple stimuli can be detected. We have done some preliminary analysis, but will have little confidence in it until the calibration questions can be resolved.